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THE EFFECT OF TWO INLET-DUCT DESIGNS ON TURBINE EFFICIENCY

By Elmer E. Trautwein and David S. Gabriel

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

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INTRODUCTION

Tests of supercharger systems have shown that impeller efficiency is considerably affected by the inlet-duct design; no published reports are available, however, to show this effect on the turbine efficiency. A surprisingly large increase in turbine efficiency resulted when the inlet-duct system for a single-stage impulse turbine with a 11.0-inch pitch-line diameter wheel was slightly altered. The alteration was made after completion of the tests reported in reference 1. The principal difference between the two inlet-duct systems is that one has an entrance section before the turbine-inlet transition piece that diverges in the direction of flow and the other has a converging section.

Efficiency curves are shown for tests with the two different entrance sections over a range of turbine-pressure ratios from 1.2 to 5.4. In addition, the results of flow surveys of the nozzle box using each of the entrance sections are shown.

APPARATUS AND TEST METHODS

A single-stage impulse turbine having an 11.0-inch pitch-line diameter wheel with inserted buckets and a fabricated nozzle diaphragm was tested. Two nozzle-box entrance sections, one divergent and the other convergent, were used. The divergent entrance section, hereinafter designated entrance section A, is shown in detail in figure 1. The test setup using entrance section A is fully described in reference 1. A detailed drawing of the convergent entrance section, hereinafter designated entrance section B, is presented in figure 2 and the test setup using entrance section B is shown in figure 1 (reference 2). Entrance section A has a divergent section in the pipe line ahead of the nozzle-box-inlet transition piece; entrance section B has a convergent section in the same relative position.

The driving fluid was atmospheric air drawn through the turbine by the laboratory altitude-exhaust system. The air flow was measured by a standard A.S.M.E. orifice in the pipe line leading to the exhaust-gas producer. The exhaust-gas producer was installed in the line to complete the inlet system but was not used to produce exhaust gas in the tests reported herein.

An NACA dynamometer-torque indicator (reference 3) was used in the tests instead of the beam scales used in reference 1.

Efficiency tests were made with entrance section B at 10 pressure ratios over a range from 1.2 to 5.4 for a constant inlet pressure of approximately 27 inches of mercury absolute and a constant inlet temperature of approximately 550° R. The turbine-wheel speed was varied from approximately 3,000 to 21,000 rpm at each pressure ratio to give blade-to-jet speed ratios from 0.1 to 0.7. An additional efficiency test was made at one pressure ratio replacing entrance section B with entrance section A.

Several check runs were made including checks on torque, air-flow measurements, and air leakage to verify the test results. The air leakage was found to be less than 1 percent of the air flow. The methods of experimental procedure and calculation are the same as those used in reference 1. As an additional check on the results, total-head surveys were made of the flow from the nozzle box with each of the inlet pipes attached.

RESULTS AND DISCUSSION

The following symbols are used in the curves showing turbine performance:

p_d turbine-discharge static pressure, inches of mercury absolute

p_i turbine-inlet total pressure, inches of mercury absolute

p_n nozzle-discharge static pressure for surveys with wheel removed, inches of mercury absolute

p_n' nozzle-discharge total pressure for surveys with wheel removed, inches of mercury absolute

u turbine-blade pitch-line velocity, feet per second

V theoretical nozzle-jet velocity, feet per second

η turbine efficiency based on the available energy calculated from the inlet-total pressure and temperature and the discharge-static pressure

The turbine efficiency is plotted in figure 3 against blade-to-jet speed ratio for turbine-pressure ratios p_1/p_d of 1.43 to 3.27. The curves of figure 4 show the maximum turbine efficiency for both entrance sections at each pressure ratio plotted against the turbine-pressure ratio. The maximum turbine efficiency using entrance section B is approximately 4 percent higher than the maximum turbine efficiency using entrance section A from a pressure ratio of 1.2 to 2.1; the difference is approximately 4.8 percent from a pressure ratio of 3.0 to 4.0. The maximum turbine efficiency for tests with entrance section B is approximately 66.3 percent for pressure ratios from 3.0 to 3.8 and approximately 61.5 percent for entrance section A for pressure ratios from 3.0 to 4.6. The data for entrance section A were taken from reference 1.

The turbine wheel was removed and a continuous total-pressure survey of the flow from the nozzle box was made. The equipment for this test was a total-head tube mounted on an arm and held parallel to the nozzle blades. The traverse total-head tube moved circumferentially at a radius halfway between the inner and outer radii of the nozzle diaphragm and at a distance of 0.1 inch downstream from the nozzles. The tube was connected to a pressure recorder, which recorded the pressures on a chart that moved with a speed synchronized with the traverse tube. Figure 5 is a plot of $(p_n' - p_n)/(p_1 - p_n)$ averaged across each individual nozzle and plotted against the position of the nozzle on the nozzle diaphragm. The losses for entrance section A are generally higher than for entrance section B, although the range from nozzles 11 to 17 shows no appreciable difference. In general, the shape of the two curves are similar and both show the same high-loss region from nozzles 25 to 35.

The average of the ratio $(p_n' - p_n)/(p_1 - p_n)$ with respect to circumferential distance along the line on which the pressure traverse was made is shown in figure 6. The curve for entrance section B shows values of $(p_n' - p_n)/(p_1 - p_n)$ about 9 percent higher than the values shown for entrance section A. This 9-percent difference in mean total pressure is higher than the difference found for turbine efficiencies. The difference in the values of $(p_n' - p_n)/(p_1 - p_n)$ would be less than 9 percent if averages of surveys from inner to outer radii of the nozzle diaphragm had been plotted.

It is apparent from the tests that the observed difference in turbine efficiency is only an effect of the entrance-section design.

SUMMARY OF RESULTS

Tests on a single-stage impulse turbine with an 11.0-inch pitch-line diameter wheel having a fabricated-nozzle diaphragm and a wheel with inserted buckets have shown a difference of 3.0 to 4.8 percent in turbine efficiency with inlet-duct systems of two different designs. The maximum efficiency for the divergent entrance section was approximately 61.5 percent from a pressure ratio of 3.0 to 4.6 and approximately 66.3 percent from a pressure ratio of 3.0 to 3.8 for the converging entrance section.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Gabriel, David S., and Carman, L. Robert: Efficiency Tests of a Single-Stage Impulse Turbine Having an 11.0-Inch Pitch-Line Diameter Wheel with Air as the Driving Fluid. NACA ACR No. E5C30, 1945.

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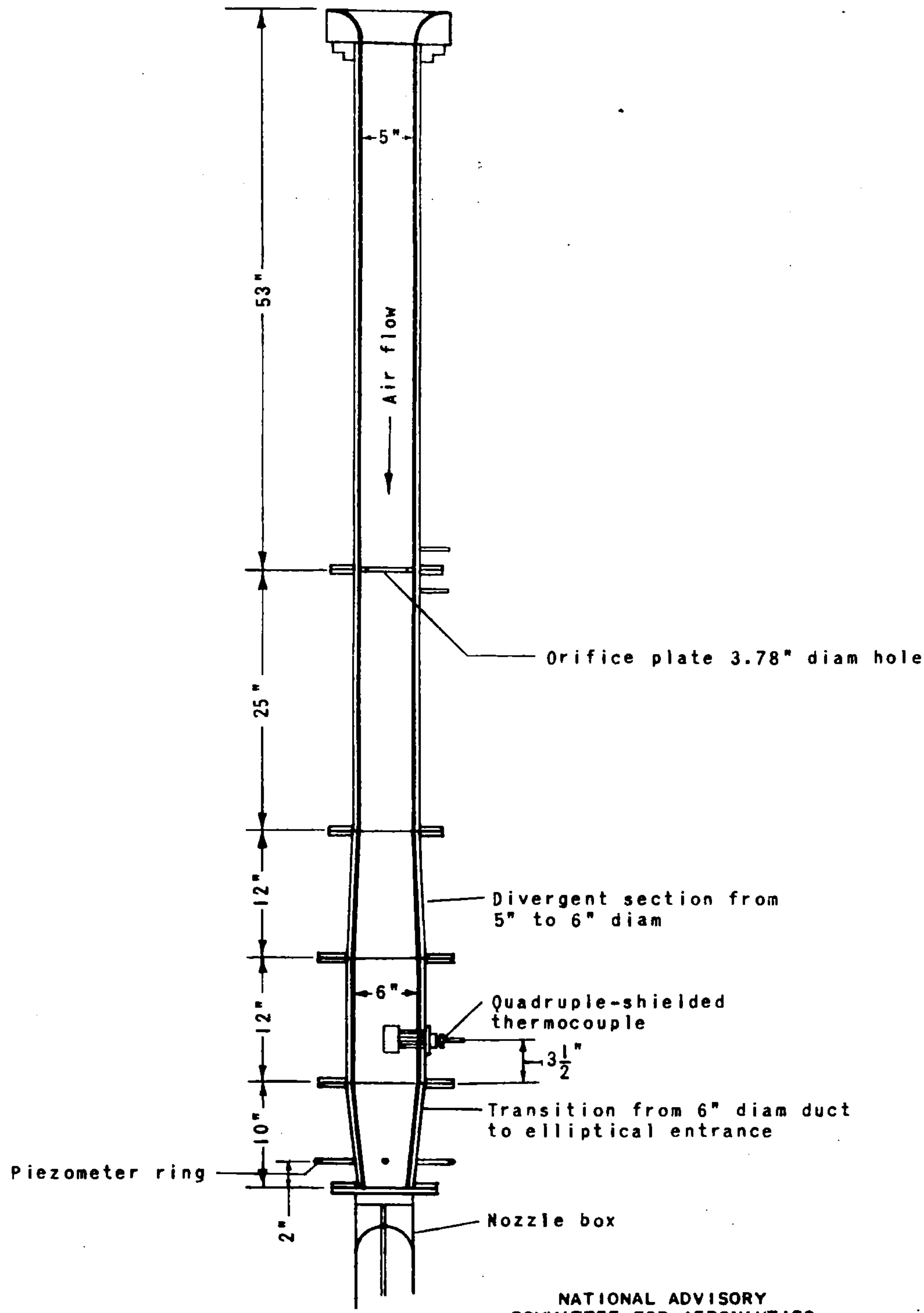

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Figure 1. - Detail of divergent entrance section A.

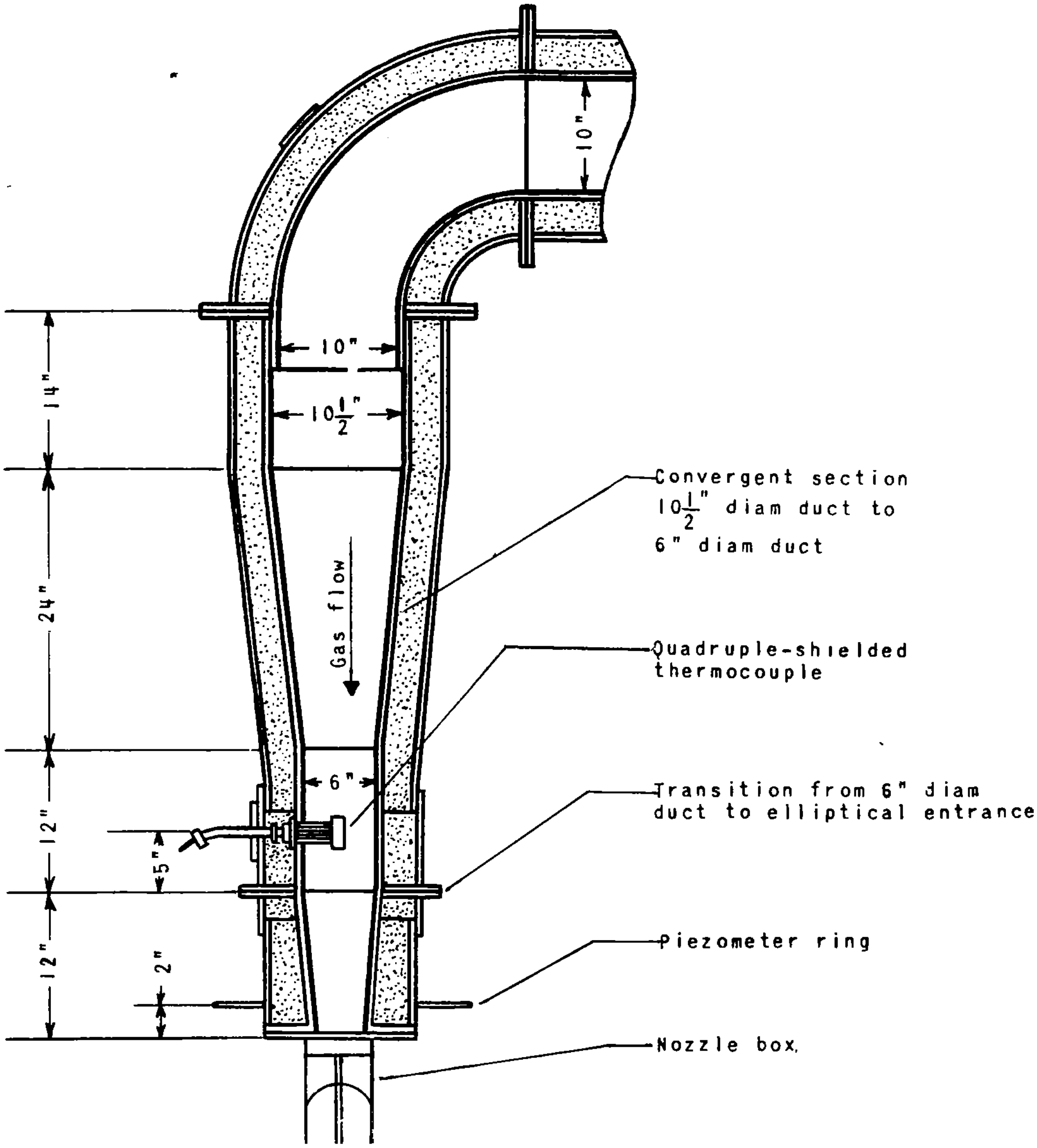

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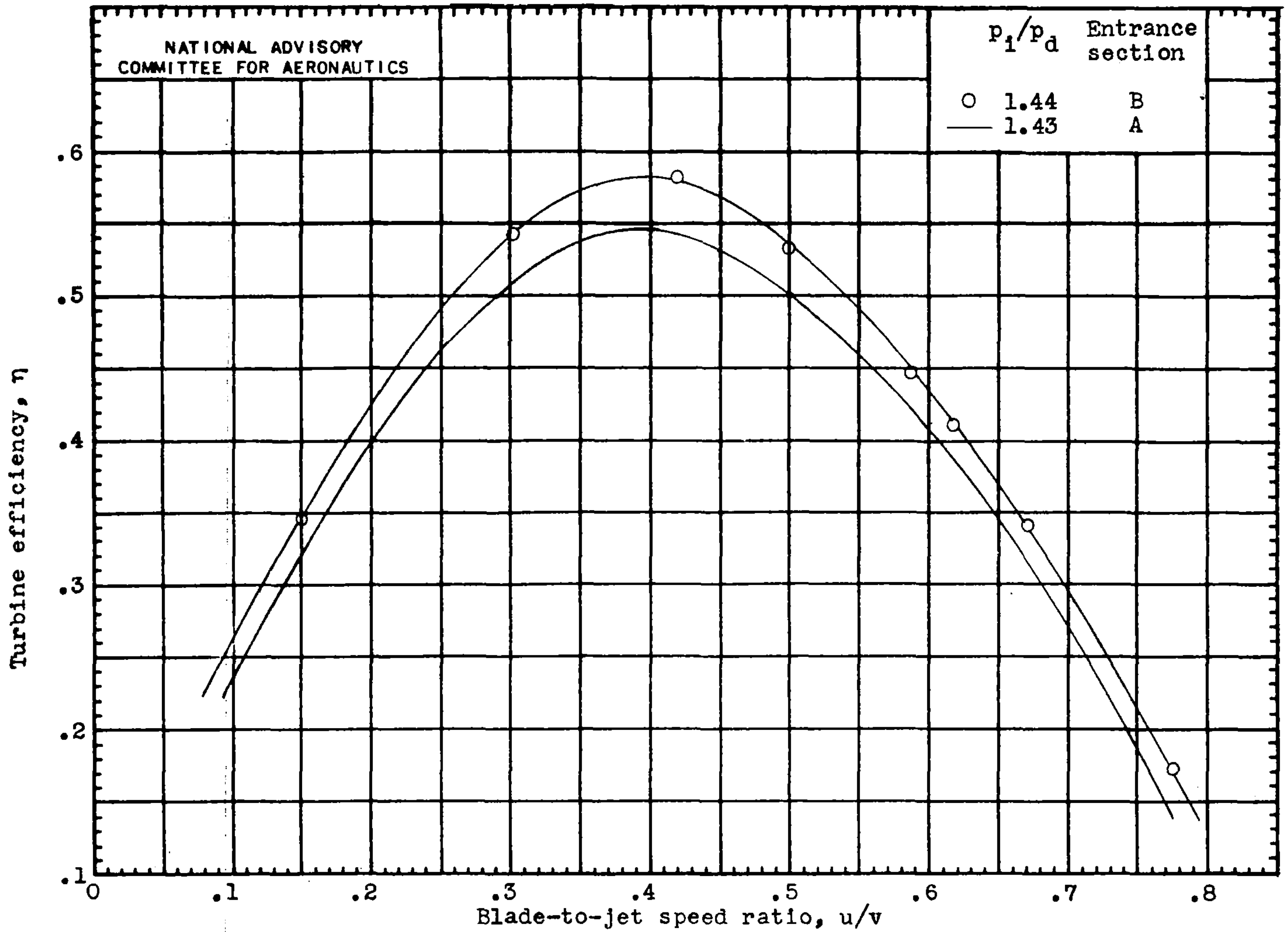
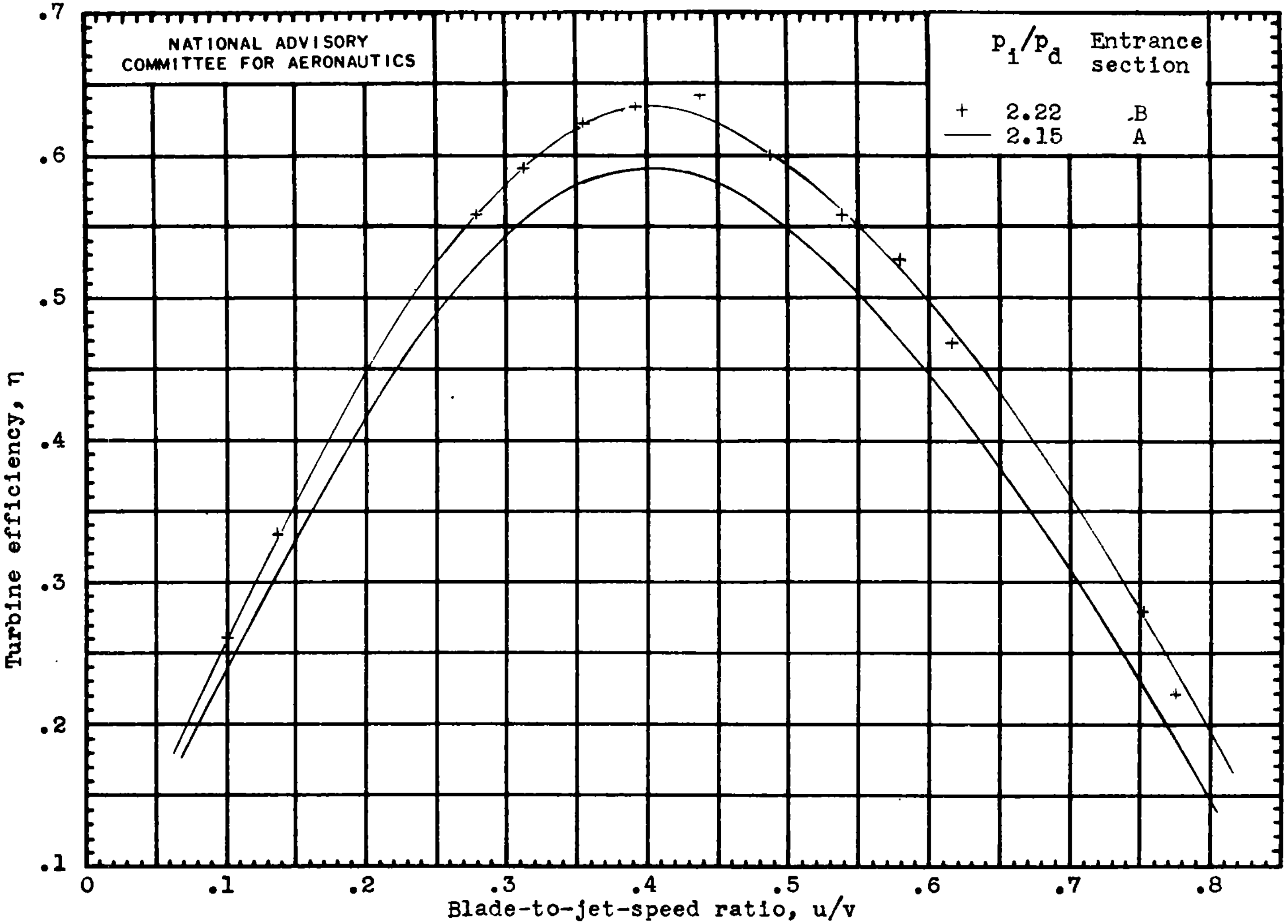
Figure 2. - Detail of convergent entrance section B.



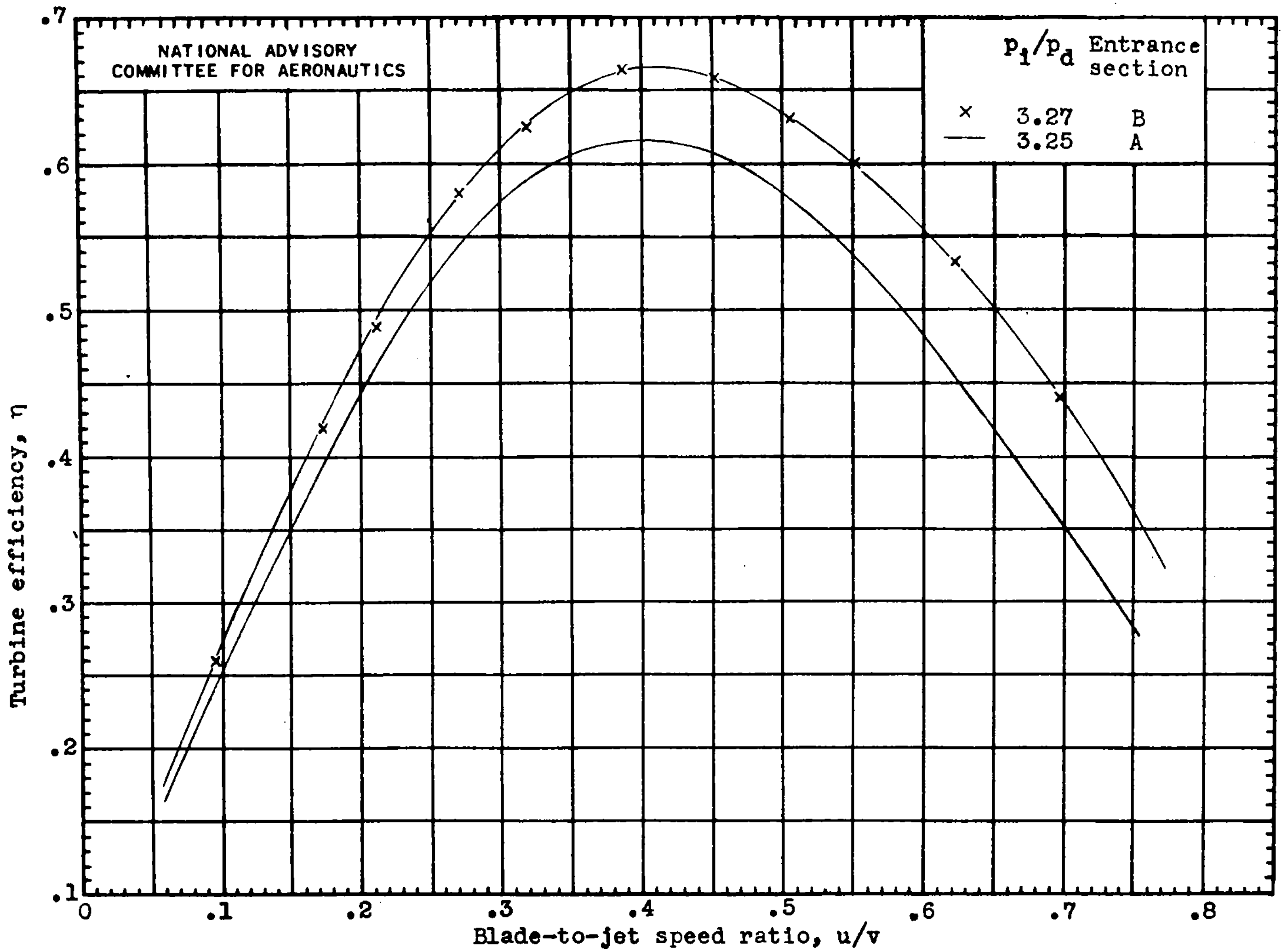
(a) Turbine-pressure ratio p_i/p_d approximately 1.4.

Figure 3. - Variation of turbine efficiency with blade-to-jet speed ratio for two entrance sections.



(b) Turbine-pressure ratio p_i/p_d approximately 2.2.

Figure 3. - Continued. Variation of turbine efficiency with blade-to-jet speed ratio for two entrance sections.



(c) Turbine-pressure ratio p_i/p_d approximately 3.3.

Figure 3. - Concluded. Variation of turbine efficiency with blade-to-jet speed ratio for two entrance sections.

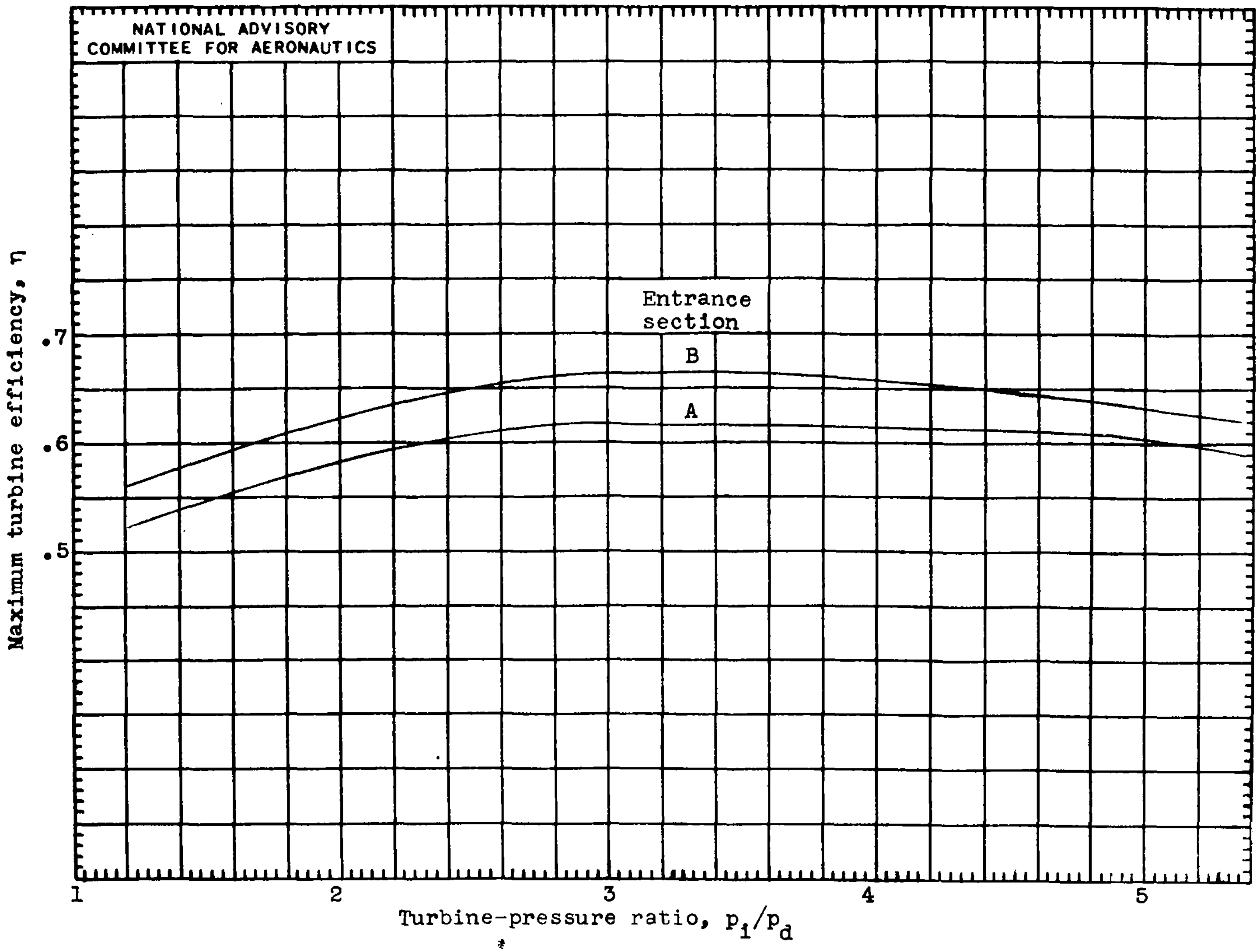


Figure 4. - Variation of maximum turbine efficiency with turbine-pressure ratio for two entrance sections. (Data for entrance section A from reference 1.)

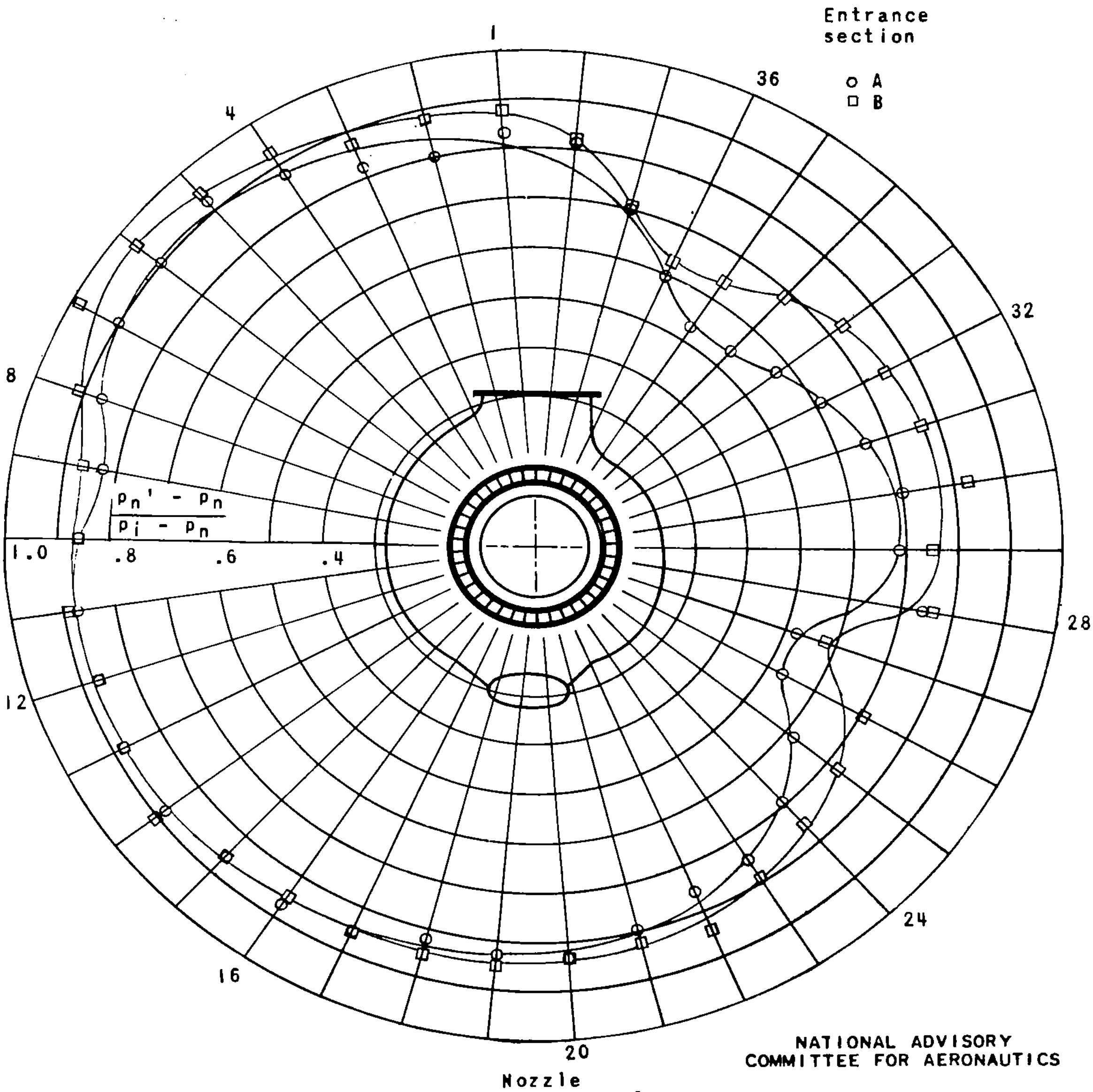


Figure 5. - Variation of ratio $\frac{p_n' - p_n}{p_i - p_n}$ with position of nozzle on diaphragm. Pressure ratio p_i/p_n, 2.09.

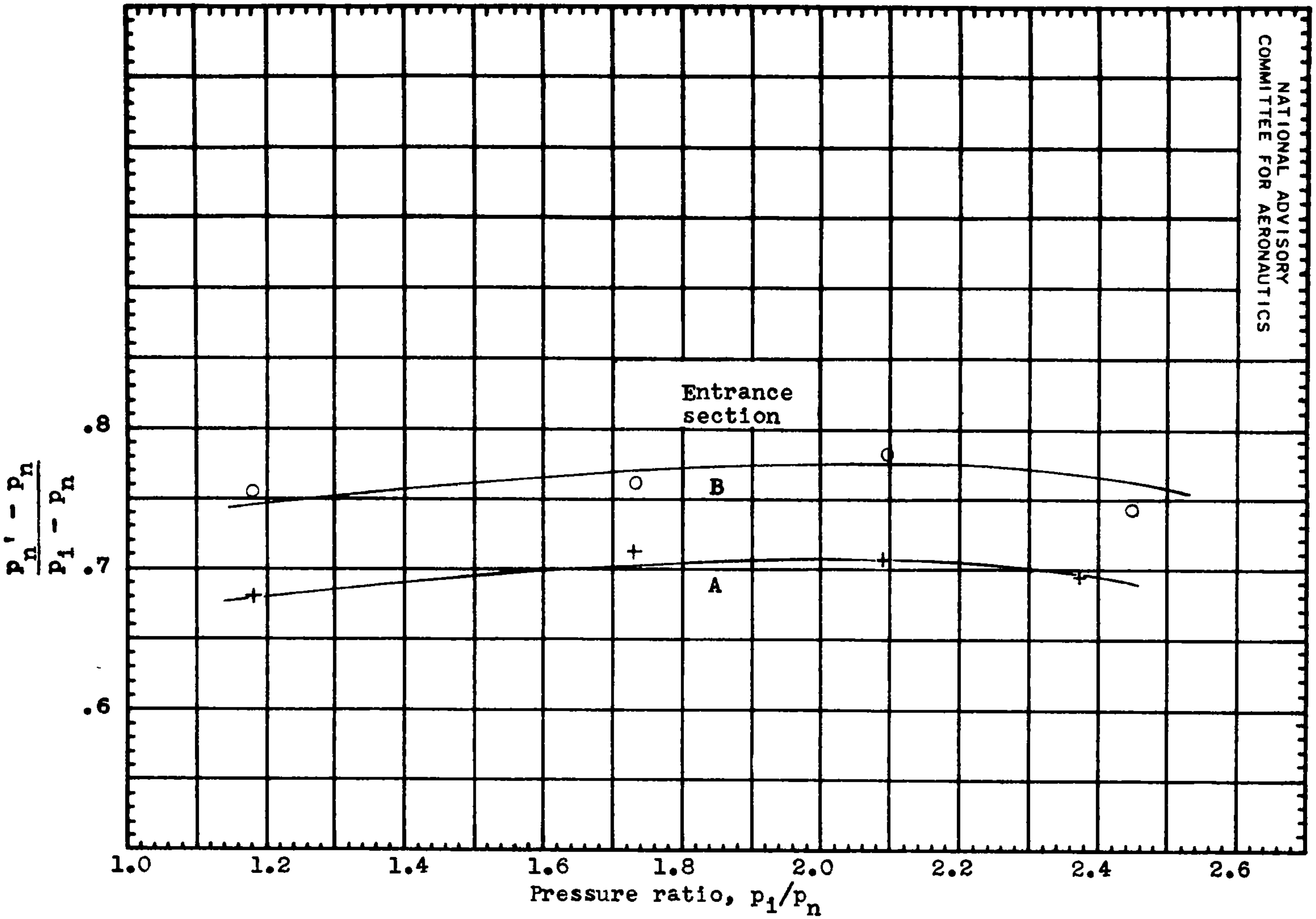


Figure 6. - Variation of the ratio of the velocity head at the nozzle discharge to the difference between total-head pressure at inlet and static-discharge pressure with pressure ratio.